

Banking crises and government intervention

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ABSTRACT

Intervention has taken different forms in different countries and periods of time. Moreover, recent episodes showed that in front of an imminent crisis, the promise of no interventions made by governments is barely credible. In this paper we address the problem of resolving banking crises from the government perspective, taking into account the fact that preventing banking crises is crucial for the government. In addition, we introduce the moral hazard problem, inherent in the banking system, and consider the interaction between regulation, policy measures and banks' behavior. To the best of our knowledge, this is the first paper that compares different policy plans to resolve banking crises in an environment where insufficiently capitalized banks have incentives to take risk, and the government has to decide whether to provide public services or impede crises. We show that when individuals highly value public services then the best policy in terms of welfare is to apply the tax on early withdrawals, as the government can transfer those taxes to the whole population by investing in public services (although at some cost). Conversely, when individuals assign a low value to consuming public services, recapitalization is the dominant policy. Finally, when the probability of a crisis is sufficiently high, capital requirements should be used.

1. Introduction

The recent financial crisis has restored the debate on how to improve the stability of the financial system. Whilst economists still discuss whether bailing out the financial system is an effective way to solve a banking crisis, in most financial crises there has been some kind of government intervention to prevent a deep credit contraction and its consequences on economic growth (Laeven and Valencia, 2008). Different mechanisms have been used in practice to prevent the propagation of crises, but all of them are costly and their effectiveness is at least uncertain.

Moreover, recent episodes showed that in front of an imminent crisis, the promise of no intervention made by governments is barely credible. Bailout policies create moral hazard problems, and this misbehavior has been pointed out at the core of the recent financial crisis.

There is therefore a general agreement on the need to limit the risk that banks take in order to have a stable system. One of the measures adopted by banking regulators in the mid-1980s was capital requirements, based on risk-weighted assets. These requirements restrict the leverage of the entity and induce banks to internalize a greater proportion of the risk of their assets. That is the essence of The Basel I Agreement. The beneficial effects that capital requirements have to reduce the likelihood of bank failure have been widely discussed from a micro-theoretical point of view. The main idea behind these studies is that increased capital requirements induce banks to take less risk. It is generally argued that if shareholders have a larger stake in the bank, the incentives to engage in risk are lower because shareholders are less likely to be bailed out than depositors.

Establishing capital requirements is also one of the three pillars of macro-prudential regulation.² In this paper we address the

² In 2008, the Basel Committee introduced a new capital called the Basel II agreement. This new agreement is based on three pillars and aims to improve over the previous one. The first pillar introduces capital requirements. In particular, two approaches are considered in order to calculate the risk-weighted assets. The standardized approach is similar to the previous agreement, except that it has more categories and uses qualifications of external credit quality. Instead, the Internal

problem of resolving banking crises from the government perspective, taking into account the fact that preventing banking crises is crucial for the government. Then, the government, when analyzing the best policy response, considers the “no-rescue” option just as a benchmark. In addition, we introduce the just mentioned moral hazard problem, inherent in the banking system, and consider the interaction between regulation, policy measures and banks’ behavior.

We model an economy with a continuum of risk-averse agents (or depositors) and risk-neutral investors (or bankers). Consumers have the standard Diamond–Dybvig preferences. In addition, there is a government that raises taxes so as to provide public services, as for instance education, health, social security, national security, recreation activities, etc. These taxes can be alternatively used to provide some safety net to the banking system at a cost of consuming less public goods. Banks have access to illiquid long term investment projects, that allow depositors to increase their expected welfare. Bankers, anticipating a government bail out in case of a banking crisis, might also invest in a gambling asset when they are insufficiently capitalized. In particular, at $t=0$, banks can choose between a safe asset or a risky one (the gambling asset) that yields a lower expected return. In order to introduce the moral hazard problem we assume that the gambling asset produces an additional unobservable return, which can be appropriated by the bankers. At $t=1$, a proportion of depositors acquires information about banks’ investments and may run on the bank, upon receiving negative information, leading to a banking crisis. We then analyze the effectiveness of the different policy measures available to the government for preventing systemic banking crises such as using taxpayers money to recapitalize banks, taxes on early withdrawals,³ or increasing capital requirements.

The government faces a clear trade-off when choosing the optimal rescue package since some policies impede crises at the expense of the provision of public services (recapitalization), whereas others (the tax on early withdrawals or capital requirements) impose restrictions on the consumption of private goods, but do not affect the consumption of public ones. We show that when individuals highly value public services then the best policy in terms of welfare is to apply the tax on early withdrawals, as the government can transfer those taxes to the whole population by investing in public services (although at some cost). Conversely, when individuals assign a low value to consuming public services, recapitalization is the dominant policy. Finally, when the probability of a crisis is sufficiently high, capital requirements should be used.

This paper is related to several articles in the banking literature. Diamond and Dybvig (1983) were the first to introduce

the idea of banks as liquidity providers, although in their model bank runs take the form of sunspots. In that respect, our paper is closer in spirit to the information literature where bank runs are information-induced (Chari and Jagannathan, 1988; Allen and Gale, 1998; Hasman and Samartín, 2008). Gorton (1988) in an empirical study of bank runs in the US during the National Banking Era (1863, 1913), found support for the notion that bank runs tended to occur after business cycle peaks. In particular, we build on the model by Brusco and Castiglionesi (2007) that analyzes the interaction between liquidity-constrained, risk-neutral bankers and risk-averse depositors, in a context of moral hazard. We modify their framework by introducing a government that raises taxes so as to provide public services (as in Hasman et al., 2011). As a consequence, the funds disposable for the private activity are reduced, which allows us to endogenize the origin of funds for the bail out plans. In this way, the government might try to prevent crises that imply the inefficient liquidation of projects.

Some of the policies analyzed in this paper have already been examined in previous papers, but each has been examined isolated from the rest, i.e., as an unique policy tool. For example, as mentioned above, the positive effects of capital requirements on risk have been widely analyzed from a theoretical point of view (see Buser et al., 1981; Furlong and Keeley, 1989; Hellman et al., 2000; Repullo, 2004 or Morrison and White, 2005). Nevertheless, other studies (see Blum, 1999 or Koehn and Santomero, 1980) have reached the opposite result. Overall, the theoretical literature has raised doubts about the effects of capital requirements on risk (Gale, 2010) and it has not proved to be completely effective in preventing bank failure, and indeed there is still a debate on whether it is or not an efficient policy (Hellman et al., 2000). In our model, capital requirements eliminate the moral hazard problem, but at a cost. As the amount of capital is exogenously given, the only way to fulfill the capital requirement is by increasing reserves, and hence, less resources can be invested in the long-term asset.

Recent contributions have also focused on bailout policies. These papers show that bailouts suffer from time inconsistency which induces banks’ moral hazard in the form of high leverage, high-risk correlation and little liquidity holding (Acharya et al., 2007, 2011; Ennis and Keister, 2010; Farhi and Tirole, 2012; Jeanne and Korinek, 2013). Our paper takes a different approach, we assume that there is moral hazard due to an environment with insufficiently capitalized banks. We also assume that commitment is impossible and so neither depositors nor the government can solve the inherent moral hazard problem. In this framework, we then compare among different intervention measures, bailout policies (in the form of recapitalization), the tax on early withdrawals or capital requirements, that will have different cost effects, represented by either a lower provision of the private or the public good.⁴ In this sense, the objective of the government is just to prevent runs, in order to give stability to the banking system.

To the best of our knowledge, this is the first paper that compares different policy plans to resolve banking crises, in an environment where insufficiently capitalized banks have incentives to take risk, and the government has to decide whether to provide public services or impede crises.

The rest of the paper is organized as follows. Section 2 presents the basic features of the model. Section 3 examines the social optimum. Section 4 analyzes the bank problem with moral hazard, and several intervention measures to prevent banking crises.

Risk Approach (IRB) differs completely from the previous agreement, as now the institution uses its own risk model. The second pillar deals with the regulatory response to the first pillar. The third pillar aims to complement the minimum capital requirements and supervisory review process by developing a set of disclosure requirements which will allow the market participants to gauge the capital adequacy of an institution. For more details, see Basel Committee on Banking Supervision (2004).

³ The existence of a tax on early withdrawals creates incentives to use the assets that are not taxed, and as a result might decrease the incentives to run on banks. We study taxes on financial transactions that existed in some developing countries like Argentina, Brazil, Colombia and Serbia. These taxes, that are levied on every transaction, including bank accounts, have been used extensively in emerging markets not necessarily to prevent bank runs, as we analyze in this paper, but as a way to obtain government funding. Taxes on financial transactions represented an important source of funding for those governments (22,471.9 millions of dollars for Brazil and around 2700 millions of dollars for Argentina in 2007), and can be considered as a special case of the tax on early withdrawals. Even the United States during the period (1932–1934) levied a two-cent tax on bank checks (Lastrapes and Selgin, 1997).

⁴ Corbett and Mitchell (2000) assume that public recapitalization (see also Mitchell, 2001 and Osano, 2002) of failing banks is equivalent to a subsidy, however Hasman et al., 2011 show that this is not necessarily true due to the opportunity cost of those funds.

Section 5 examines the bank problem when capital requirements are introduced. Section 6 provides some numerical simulations and finally, Section 7 summarizes the concluding remarks.

2. The model

This is a three-date (0, 1, and 2) and one-good economy. The model is based on Brusco and Castiglionesi (2007), with only one region, but with taxation and provision of public goods by the government and information on the side of depositors. There is a continuum of risk-averse agents (or depositors) and risk-neutral investors (or bankers), both of measure one. Depositors are endowed with one unit of the good at $t=0$, while investors are endowed with e units (with $e < 1$). Finally, there is a government that raises a lump-sum tax T at $t=0$ and can provide public services at $t=1$ or at $t=2$.⁵ We assume that providing public services late is costly. The government can transform one unit of taxes at $t=0$ into one unit of public goods at $t=1$ or $\kappa < 1$, at $t=2$.⁶ Note that total funds raised by the government are $T(1+e)$, where T comes from depositors and Te from investors.

Agents (i.e., depositors) are identical at $t=0$, but they can become type-1 or impatient (with probability γ) and thus derive utility from consumption at $t=1$, or type-2 or patient (with probability $1-\gamma$) and thus derive utility from consumption at $t=2$ (Diamond-Dybvig preferences). Let c_t denote the consumption of the depositor at time $t=1, 2$. Then, the utility of depositors can be represented by the following utility function:

$$U(c_1, c_2, T) = \begin{cases} u(c_1) + \theta u[T(1+e)] & \text{with probability } \gamma \\ u(c_2) + \theta u[T(1+e)] & \text{with probability } (1-\gamma) \end{cases} \quad (1)$$

where the utility function $u(\cdot)$ is defined over non-negative levels of consumption; $u(\cdot)$ is strictly increasing, strictly concave, twice continuously differentiable, and satisfies Inada conditions. Additionally, it is assumed that $u(0)=0$. The parameter $\theta > 0$ is a measure of the efficiency of the government in the provision of public services. The type of the agent is her private information.

We consider risk-neutral investors (or bankers). These investors can either consume at $t=0$ (c_0), or buy shares from the banks, in which case they receive dividends d_t at $t=1, 2$. The utility function of the bankers is as follows:

$$U(c_0, d_1, d_2, T) = Rc_0 + d_1 + d_2 + \theta T(1+e) \quad (2)$$

Since investors can obtain a utility of Re by immediately consuming their endowment, they have to be rewarded at least R for each unit of consumption they give up today. The incentive constraint for the bankers is then: $d_2 \geq Re(1-T)$.

We assume that bankers have a comparative advantage in investing, which induces agents to deposit their endowment in banks (so as to benefit from that advantage). In particular, bankers have access to three different investment projects. A short-term asset or storage that takes one unit at date t and transforms it into one unit at $t+1$. A long-term and safe project that transforms one unit at $t=0$ into $R > 1$ units at date $t=2$. Finally, there is a second long-term asset, the gambling asset, that transforms one unit at

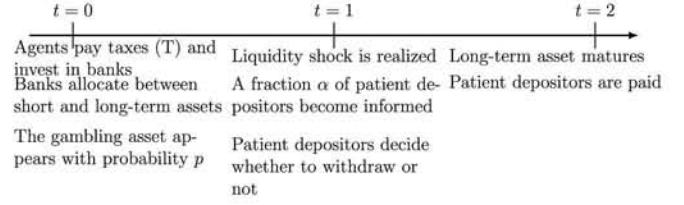


Fig. 1. Sequence of events.

$t=0$ into R units with probability η and 0 with probability $(1-\eta)$, at $t=2$. Both of the long term technologies are illiquid at $t=1$, or equivalently, their liquidation value is close to zero. In order to introduce a moral hazard problem we assume that the gambling asset produces unobservable private benefits for the investors of an amount $(\lambda-1)R$, for each unit invested at $t=0$, that are not observable to depositors. Due to the limited liability assumption, depositors receive zero when the gambling asset does not succeed. Finally, the opportunity of investing in the gambling asset appears with probability p and is not verifiable.⁷

To complete the model, we assume that a proportion α of patient depositors receives information about the appearance of the gambling asset at $t=1$.

The sequence of events is as follows: at $t=0$, agents pay taxes and invest the rest of their endowment in banks. Banks then distribute this amount between the short and the long-term investments. At $t=1$, agents decide whether to withdraw their money from banks (given the liquidity and information shocks), and consume public services. At $t=2$, the long-term project matures and patient depositors are paid. Fig. 1 illustrates the timing of the model.

3. The social planner problem

As a useful benchmark, we start solving the first-best allocation. We can focus on the representative consumer, since they are all ex-ante identical. In addition, as there is no aggregate uncertainty, the optimal consumption will be independent of the state.

Clearly, there will be no gambling in the Pareto-optimal allocation and consequently, the amount of capital owned by the risk-neutral investors is indeterminate. They can either consume their endowment at $t=0$ or give it to be distributed by the planner. Instead, the amount of capital does play a role in the decentralized economy, as we show in the following sections.

The social planner will solve the following problem:

$$\max_{\{x, y, c_1, c_2\}} \gamma u(c_1) + (1-\gamma)u(c_2) \quad (3)$$

subject to

$$x + y \leq 1 - T \quad (4)$$

$$\gamma c_1 \leq y \quad (5)$$

$$(1-\gamma)c_2 \leq Rx \quad (6)$$

$$x, y, c_1, c_2 \geq 0 \quad (7)$$

where y is the amount invested in the short-term asset, x is the amount invested in the long-term safe technology, and c_1 and c_2

⁵ We consider an exogenous T to present the fact that levying and spending decisions, may be independent, from the government point of view. This exogenous T can be the maximum of the Laffer curve, for example. How to spend those resources, is a different issue, and the government can have a better control on them, (as happens in our model, when it decides to recapitalize banks).

⁶ The value κ works as a discount factor meaning that there are costs associated to providing and consuming public goods later (postponing the construction of schools, hospitals, highways might create serious problems to the society).

⁷ The moral hazard problem is introduced as in Brusco and Castiglionesi (2007). We assume that the bank can just choose between a long safe asset or a risky one. We admit the simplicity of our assumption. Nevertheless, the qualitative nature of our results would not change, if we introduce assets with different levels of risk. Note that moral hazard in our paper is generated due to the existence of non observable returns on the riskier asset that can be only appropriated by investors.

are the levels of consumption offered to each impatient and patient depositor respectively.

Eq. (3) is the expected utility to be maximized. Eq. (4) is the budget constraint at $t=0$; it states that all resources (after taxes) should be divided between the short and the long-term investment. Eq. (5) is the first-period constraint, and says that all the resources from the short asset should be used to pay the impatient depositor. Eq. (6) is the second-period constraint, where resources invested in the long-term technology are used to pay the patient depositor.

Optimality requires that the feasibility constraints are satisfied with equality, so we can write the problem as

$$\max_{y \in [0,1]} \gamma u\left(\frac{y}{\gamma}\right) + (1-\gamma)u\left(\frac{1-T-y}{1-\gamma}R\right) \quad (8)$$

Since $u(\cdot)$ is strictly concave and satisfies the Inada conditions, the solution to problem (8) is unique and interior. The optimal value $y^* \in (0, 1)$ is obtained from the first order condition

$$u'\left(\frac{y^*}{\gamma}\right) = Ru'\left(\frac{1-T-y^*}{1-\gamma}R\right) \quad (9)$$

and once y^* has been determined by Eq. (9) we can use the feasibility constraints to determine the other variables:

$$c_1^* = \frac{y^*}{\gamma}, \quad c_2^* = \frac{(1-T-y^*)}{1-\gamma}R, \quad x^* = 1-T-y^* \quad (10)$$

Notice that (9) and (10) imply that $u'(c_1^*) = Ru'(c_2^*)$, which in turn implies $u'(c_1^*) > u'(c_2^*)$ and $c_2^* > c_1^*$. Thus, the first-best allocation automatically satisfies the incentive constraint $c_2 \geq c_1$, i.e., the late consumer has no incentive to behave as the early one. Let $\Psi^* \equiv (y^*, x^*, c_1^*, c_2^*)$ denote the first-best allocation, and U^* the expected utility achieved under the first-best allocation.

We can define the following welfare function, that takes into account the consumption of the exogenous amount of the public good:

$$U_{SOC} = w\{U^* + \theta u[T(1+e)]\} + (1-w)\{Re(1-T) + \theta[T(1+e)]\} \quad (11)$$

where we assume that each type of agent's expected utility is weighted in the welfare function according to a value w .

4. Bank problem with moral hazard

4.1. Condition for banks to gamble

The formal condition for banks to gamble is derived as follows:

Note that when banks invest in the long-term and safe asset, the return is Rx . Additionally, dividends are paid only at $t=2$, since in this way capital can be invested in the (more profitable) long-term asset rather than in the short asset. Bankers receive what is left after paying patient depositors. Therefore, the second period dividend is:

$$d_2 = Rx - (1-\gamma)c_2 \quad (12)$$

Competition among investors implies that they should receive from banks exactly what they would get without investing in banks, as a result the incentive constraint is satisfied with equality:

$$d_2 = Re(1-T) \quad (13)$$

On the other side, if the bank invests everything in the gambling asset, then the dividend will depend on the realization of the gambling asset in the following form:

$$\tilde{d}_2 = \begin{cases} \lambda Rx - (1-\gamma)c_2 & \text{with probability } \eta \\ (\lambda-1)Rx & \text{with probability } (1-\eta) \end{cases} \quad (14)$$

The above equation says that when the gambling asset succeeds, with probability η , the investor receives what is left after paying the depositor. When the gambling asset does not succeed, with probability $1-\eta$, the investor just receives the unobservable return from gambling.

From (14), and making use of (12) and (13) we have:

$$\begin{aligned} E[\tilde{d}_2] &= \eta[(\lambda-1)Rx + d_2] + (1-\eta)[(\lambda-1)Rx] \\ &= (\lambda-1)Rx + \eta Re(1-T) \end{aligned} \quad (15)$$

consequently, the bank will choose the safe asset whenever:

$$Re(1-T) \geq (\lambda-1)Rx + \eta Re(1-T) \geq (1-\eta)Re(1-T) \geq (\lambda-1)Rx \quad (16)$$

Letting $\xi \equiv (\lambda-1)/(1-\eta)$, we have:

Lemma 1. *If the deposit contract offers a level of long-term investment x , then the bank will invest in the gambling asset only if the bank's capital is*

$$e < \frac{\xi x}{(1-T)} \quad (17)$$

From now on we assume that the exogenous level of capital is low so that Lemma 1 holds and banks have incentives to invest in the gambling asset.⁸

We are interested in analyzing a framework where there are moral hazard problems on the side of investors. In general, moral hazard can be completely eliminated if it is possible to sufficiently capitalize the banks. Thus, the crucial ingredient for achieving this result is the existence of some cost, to depositors, of capitalizing banks. That is why we assume, as in Brusco and Castiglionesi, that the amount of capital is limited.

4.2. Deposit contract with bank runs

This section characterizes the deposit contract, when banks rationally take into account the possibility of a bank run. Let us assume that banks offer the contract c_1, \tilde{c}_2 at $T=0$, where \tilde{c}_2 is equal to c_{2L} , if the gambling asset fails (which is zero, if there is no storage between dates 1 and 2) and c_{2H} , when it succeeds. At $T=1$, the sequence of events is as follows: first, the appearance of the gambling asset is observed by informed depositors. These depositors will not run on the bank as long as the utility of withdrawing is lower than the expected utility of waiting, i.e.,

$$u(c_1) \leq \eta u(c_{2H}) + (1-\eta)u(c_{2L}) \quad (18)$$

If the above condition is not satisfied, there are runs on the bank. Formally, the condition for depositors to run on the bank is summarized in Lemma 2.

Lemma 2. *Let $\hat{\eta}$ be the level of η for which the incentive constraint given by (18) is binding. Then, for $\eta < \hat{\eta}$, the incentive constraint is violated and there are runs.*

⁸ Note that this condition is similar to the one obtained by Brusco and Castiglionesi (2007) in a framework without taxes.

We assume that Lemma 2 holds, i.e., the exogenous value of η is sufficiently low (below $\hat{\eta}$), so there are always runs.⁹

As the type of the consumer is private information, the bank cannot distinguish between type-1 agents or informed-type-2. Additionally, agents arrive at the bank and are paid sequentially, therefore, this first-come-first-served service plus the illiquidity of the long-term investment, makes the bank subject to runs whenever the proportion of withdrawals at $t=1$ is greater than γ .

Let the probability of being paid, when the gambling asset appears, be $\pi = \gamma / (\alpha(1-\gamma) + \gamma)$, where the numerator represents total supply (the bank can only pay c_1 to γ agents), and the denominator total demand (type-1 consumers and informed-type-2). So with probability π , type-1 and informed type-2 receive c_1 , and with probability $(1-\pi)$, they will receive zero.

As banks operate in a competitive environment, they will maximize the expected utility of the consumer subject to the resource constraints. The optimal contract, at $T=0$, is then obtained as follows:

$$\max_{\{x, y, c_1, c_2, d_1, d_2\}} (1-p)[\gamma u(c_1) + (1-\gamma)u(c_{2H})] + p\gamma u(c_1) \quad (19)$$

subject to

$$\gamma c_1 + d_1 \leq y \quad (20)$$

$$(1-\gamma)c_{2H} + d_2 \leq Rx + y - \gamma c_1 - d_1 \quad (21)$$

$$(1-\gamma)c_{2L} \leq y - \gamma c_1 - d_1 \quad (22)$$

$$d_1 + (1-p)d_2 + p(\lambda-1)Rx \geq Re(1-T) \quad (23)$$

$$x + y \leq (1-T)(e+1) \quad (24)$$

where as before y is the amount invested in the short term asset, x is the amount invested in the gambling asset, and c_t and d_t denote the consumption of the depositor and the dividend paid to the investor at time $t=1, 2$. The interpretation of this problem is as follows: Eq. (19) is the expected utility to be maximized.

Note that when the gambling asset does not appear, consumption in both periods is as promised. When the gambling asset appears, there is a run, and depositors are paid sequentially.¹⁰ Eq. (20) is the first period constraint and Eqs. (21) and (22) the second period ones (note that resources in both periods are distributed between the depositor and the dividends to the investor, and there is the possibility to rollover resources from date 1 to date 2); Eq. (23) is the participation constraint for the investors: they receive the second period dividend when the gambling asset does not appear, and when it appears there is a run so they just retain the amount $(\lambda-1)Rx$. Finally, Eq. (24) is the budget constraint at $t=0$. Let $(c_1^{BR}, c_{2H}^{BR}, x^{BR}, y^{BR}, d_1^{BR}, d_2^{BR})$ represent the optimal solution to the above problem.

The equilibrium solution of the model can satisfy the bank-run condition, i.e., $u(c_1^{BR}) > \eta u(c_{2H}^{BR}) + (1-\eta)u(c_{2L}^{BR})$ and the gambling condition, $e < (\xi x^{BR}) / (1-T)$.¹¹

We define by U_{BR}^D the depositors' expected utility on the consumption of the private good and U_{BR}^C the investors' one.

Where

$$U_{BR}^D = (1-p)[\gamma u(c_1^{BR}) + (1-\gamma)u(c_{2H}^{BR})] + p\gamma u(c_1^{BR}) \quad (25)$$

and

$$U_{BR}^C = (1-p)d_2^{BR} + p(\lambda-1)Rx^{BR} \quad (26)$$

The social welfare function, in case of a bank run is as follows:

$$U_{BR} = w(U_{BR}^D + \theta u[T(1+e)]) + (1-w)(U_{BR}^C + \theta[T(1+e)]) \quad (27)$$

where we assume that each type of agent's expected utility is weighted in the welfare function according to a value w .

4.3. Recapitalization-deposit insurance

In this section we examine a recapitalization plan using taxpayers' money in order to stop a bank run: the government creates a buffer with taxpayers' money in order to increase the liquidity of the banking sector. However, partial liquidation of the public asset implies consuming less public services.

Note that recapitalization has a similar analysis to a deposit insurance scheme guaranteeing c_1 . Both policies will have similar results in term of welfare, the difference is that in the case of recapitalization the bank will be paying depositors while in the case of a deposit insurance scheme, it is the deposit insurance agency who would be paying depositors in case of a bank run. Consequently, recapitalization in this model could be interpreted as a deposit insurance system financed by public funds (as done in a recent paper by Allen et al., 2013).¹²

Let δ denote the total amount of money that should be injected into the banking system so as to recapitalize banks and stop the bank run, then δ is given by the following condition:

$$u(c_1) = \eta u(c_{2H}) + (1-\eta)u\left(c_{2L} + \frac{\delta}{1-\gamma}\right) \quad (28)$$

This equation ensures that the type-2 consumer is indifferent between withdrawing or not.

The optimal contract, when recapitalization is present, is obtained by solving the following problem:

$$\max_{\{x, y, c_1, c_2, d_1, d_2\}} (1-p)[\gamma u(c_1) + (1-\gamma)u(c_{2H})] + pu(c_1) \quad (29)$$

subject to

$$\gamma c_1 + d_1 \leq y \quad (30)$$

$$(1-\gamma)c_{2H} + d_2 \leq Rx + y - \gamma c_1 - d_1 \quad (31)$$

$$(1-\gamma)c_{2L} \leq y - \gamma c_1 - d_1 \quad (32)$$

$$d_1 + (1-p)d_2 + p(\lambda-1)Rx \geq Re(1-T) \quad (33)$$

$$u(c_1) = \eta u(c_{2H}) + (1-\eta)u\left(c_{2L} + \frac{\delta}{1-\gamma}\right) \quad (34)$$

$$x + y \leq (1-T)(e+1) \quad (35)$$

The objective function is interpreted as follows: with probability $(1-p)$, the gambling asset does not appear and thereby the consumption of depositors is as promised. When the gambling asset appears, which occurs with probability p , the bank run is stopped and both patient and impatient depositors obtain the same utility. Eq. (30) is the first period constraint. Eqs. (31) and (32) are

⁹ Following Allen and Gale (2007), in this paper, we focus on essential bank runs, i.e., bank runs that cannot be avoided, and therefore the necessary and sufficient condition for a bank run is that the incentive constraint be violated. We then rule out pure panic runs of the Diamond and Dybvig type.

¹⁰ With probability π , some type-1 depositors and informed type-2, will consume c_1 , i.e., $\pi[\gamma + (1-\gamma)\alpha]u(c_1)$ and with probability $1-\pi$, they arrive late at the queue, and consume 0, as the rest of uninformed type-2. Note that $\pi[\gamma + (1-\gamma)\alpha]u(c_1) = \gamma u(c_1)$.

¹¹ Additionally, if η is sufficiently low, it will never be optimal for the bank to prevent runs, by imposing the incentive-compatibility constraint, given by (18). The run-proof contract is dominated by the bank-run one. See Allen and Gale (2007) for a discussion of this issue.

¹² Recapitalization can be also assimilated to a lender of last resort action. Here, the government (might also be a central bank with similar implications) injects liquidity into the banking sector to prevent a bank run (the only way of generating a crisis at $t=1$ in this model).

the second period resource constraints, which take into account the possibility to roll over resources from date 1 to date 2. Eq. (33) is the investors' participation constraint. Finally, Eq. (34) is the condition to stop the bank run and Eq. (35) is the period zero resource constraint. Let $(c_1^R, c_{2H}^R, c_{2L}^R, x^R, y^R, d_1^R, d_2^R)$ represent the optimal solution to the above problem.

The equilibrium solution of the model can satisfy the bank-run condition, i.e., $u(c_1^R) > \eta u(c_{2H}^R) + (1 - \eta)u(c_{2L}^R)$ and the gambling condition, $e < (\xi x^R)/(1 - T)$.

The expected utility of depositors is then:

$$U_R^D = (1 - p)[\gamma u(c_1^R) + (1 - \gamma)u(c_{2H}^R)] + p u(c_1^R) \quad (36)$$

and the investors' expected utility is:

$$U_R^C = (1 - p)d_2^R + p(\lambda - 1)Rx^R \quad (37)$$

The social welfare function, in the case of recapitalization is as follows:

$$U_R = w[U_R^D + \theta[(1 - p)u(T(1 + e)) + pu(T(1 + e) - \delta) + p\eta u(\delta k)]] \\ + (1 - w)[U_R^C + \theta[T(1 + e) - p\delta + p\eta \delta k]] \quad (38)$$

Finally, it is welfare improving to stop the bank run only if U_{BR} given by Eq. (27) is less than U_R given by Eq. (38), which holds if:

$$\theta \geq \theta^R \equiv \frac{\omega(U_{BR}^D - U_R^D) + (1 - \omega)(U_{BR}^C - U_R^C)}{p\{ \omega[u(T(1 + e) - \delta) + \eta u(\delta k) - u(T(1 + e))] - (1 - \omega)[\delta - \eta \delta k] \}} \quad (39)$$

4.4. Tax on early withdrawals

The government can impose an additional tax on early withdrawals in order to decrease the incentives for type-2 depositors to withdraw at $t=1$ and thus stop the bank run. These taxes are costly for impatient depositors because they support the whole cost of preventing the crisis.¹³ The government sets up an exogenous tax δ_T on early withdrawals to prevent bank runs, i.e., the amount to be levied is $\delta_T c_1$. However, the government does not have enough information to anticipate the optimal value for δ_T , and consequently it might be too low or too high. Bank runs will be prevented when δ_T is high enough and when this is the case, the equilibrium consumption levels are such that the following condition is satisfied:

$$u(c_1(1 - \delta_T)) \leq \eta u(c_{2H}) + (1 - \eta)u(c_{2L}) \quad (40)$$

When runs can be avoided, the optimal contract, is derived as follows:

$$\max_{\{x, y, c_1, c_2, d_1, d_2, \delta_T\}} (1 - p)[\gamma u(c_1(1 - \delta_T)) + (1 - \gamma)u(c_{2H})] \\ + p[\gamma u(c_1(1 - \delta_T)) + (1 - \gamma)[\eta u(c_{2H}) + (1 - \eta)u(c_{2L})]] \quad (41)$$

subject to

$$\gamma c_1 \leq y \quad (42)$$

¹³ The tax on early withdrawals is applied in a similar way to what was done in many countries in Latino America or Eastern Europe. They include taxes on checks, debit cards or cash withdrawals. The objective is to promote the use of time accounts against current accounts and to prevent panics during periods of bad rumors about the solvency of the banking system (see the discussion in footnote 3).

$$(1 - \gamma)c_{2H} + d_2 \leq Rx + (y - \gamma c_1 - d_1) \quad (43)$$

$$(1 - \gamma)c_{2L} \leq y - \gamma c_1 \quad (44)$$

$$d_1 + (1 - p)d_2 + p(\lambda - 1)Rx \geq Re(1 - T) \quad (45)$$

$$x + y \leq (1 - T)(e + 1) \quad (46)$$

where, as mentioned above, δ_T is exogenously imposed by the government. The interpretation of the above problem is equivalent to that of the previous section.

When condition (40) is not satisfied (meaning that δ_T is set up too low), then the optimal contract will solve the following problem, that allows for runs:

$$\max_{\{x, y, c_1, c_2, d_1, d_2, \delta_T\}} (1 - p)[\gamma u(c_1(1 - \delta_T)) + (1 - \gamma)u(c_{2H})] \\ + p\gamma u(c_1(1 - \delta_T)) \quad (47)$$

subject to

$$\gamma c_1 + d_1 = y \quad (48)$$

$$(1 - \gamma)c_{2H} + d_2 \leq Rx + (y - \gamma c_1 - d_1) \quad (49)$$

$$d_1 + (1 - p)d_2 \geq Re(1 - T) \quad (50)$$

$$x + y \leq (1 - T)(e + 1). \quad (51)$$

Let $(c_1^T, c_{2H}^T, c_{2L}^T, x^T, y^T, d_1^T, d_2^T)$ represent the optimal solution when the tax on early withdrawals is imposed, with one of the two above problems.

The expected utility of depositors is:

$$U_T^D = (1 - p)[\gamma u(c_1^T) + (1 - \gamma)u(c_{2H}^T)] + p[\gamma u(c_1^T) + (1 - \gamma)u(c_{2L}^T)]$$

where $c_{1T} = c_1(1 - \delta_T)$.

And the investors' expected utility is:

$$U_T^C = (1 - p)d_2^T + p(\lambda - 1)Rx^T \quad (52)$$

The social welfare function, in the case of the tax on early withdrawals is as follows:

$$U_T = w[U_T^D + \theta[u(T(1 + e)) + u(k\gamma\delta_T)]] \\ + (1 - w)[U_T^C + \theta[T(1 + e) + k\gamma\delta_T]] \quad (53)$$

Proposition 1. *Investors will always prefer the tax on early withdrawals to all the other policies, since it increases their consumption of the public asset.*

Note that as that as investors are competitive, their expected utility of consuming the private good is always equal to their opportunity cost $(e(1 - T)R)$. The tax on early withdrawals increases their consumption of the public good in every state of nature (the tax just penalizes depositors). Then, their expected utility always increases and the demonstration is trivial.

This policy is welfare improving if U_T , which is given by Eq. (53) is higher than U_{BR} , Eq. (27), or equivalently $\theta \geq \theta^T$, where:

$$\theta^T \equiv \frac{\omega(U_{BR}^D - U_T^D) + (1 - \omega)(U_{BR}^C - U_T^C)}{\omega u(k\gamma\delta_T) + (1 - \omega)\kappa\gamma\delta_T} \quad (54)$$

Similarly, the tax on early withdrawals will be preferred to recapitalization when $U_T \geq U_R$ or, equivalently, if

$$\theta \geq \theta^{TR} \equiv \frac{\omega(U_R^D - U_T^D) + (1 - \omega)(U_R^C - U_T^C)}{\omega A + (1 - \omega)B} \quad (55)$$

where:

$$A = pu[T(1+e)] + [u(\kappa\gamma\delta_T)] - pu[T(1+e) - \delta] - p\eta u(\delta\kappa)$$

$$B = \kappa\gamma\delta_T + p(\delta - \eta\delta\kappa)$$

5. Bank problem with capital requirements

Another solution to the moral hazard problem is to require banks to be sufficiently capitalized. This requires, in the context of our model, that the no-gambling condition be imposed, i.e., $e(1-T) \geq \xi x$. This restriction implies that banks reduce the amount x earmarked for the long term investment, and hence increase the amount of reserves. Basically, as the exogenous amount of capital is limited, the only way to recapitalize banks in this model, is by increasing reserves (which implies putting less resources in the long-term asset and which is similar, in practice, to a liquidity requirement).

The bank problem, when moral hazard is prevented, can be expressed as follows:

$$\max_{\{x, y, c_1, c_2, d_1, d_2\}} \gamma u(c_1) + (1-\gamma)u(c_2) \quad (56)$$

subject to

$$e(1-T) \geq \xi x \quad (57)$$

$$\gamma c_1 + d_1 \leq y \quad (58)$$

$$(1-\gamma)c_2 + d_2 \leq Rx \quad (59)$$

$$d_1 + d_2 \geq Re(1-T) \quad (60)$$

$$x + y \leq (1-T)(e+1) \quad (61)$$

The interpretation of this problem is similar to that of Section 4, except for Eqs. (57) and (60). Eq. (57) obliges banks to be sufficiently capitalized by restricting the amount that can be invested in the long term project. Eq. (60) is the participation constraint for investors when there is no gambling. Let $(c_1^{CR}, c_2^{CR}, x^{CR}, y^{CR}, d_1^{CR}, d_2^{CR})$ represent the optimal solution to the above problem.

In this case, the depositors' expected utility on the consumption of the private good is:

$$U_{CR}^D = \gamma u(c_1^{CR}) + (1-\gamma)u(c_2^{CR}) \quad (62)$$

and the investors' utility is just:

$$U_{CR}^C = d_2^{CR} = Re(1-T) \quad (63)$$

The social welfare function, in the case of capital requirements is:

$$U_{CR} = w\{U_{CR}^D + \theta u[T(1+e)]\} + (1-w)\{U_{CR}^C + \theta[T(1+e)]\} \quad (64)$$

Proposition 2. *For a sufficiently low e , such that bankers have incentives to gamble, there exists a value of $p^* > 0$, such that if $p < p^*$, recapitalization is preferred to capital requirements.*

PROOF OF PROPOSITION. When $p \rightarrow 0$, the social welfare function with recapitalization, Eq. (38), becomes:

$$U_R = w\{U_R^D + \theta u[T(1+e)]\} + (1-w)\{U_R^C + \theta[T(1+e)]\} \quad (65)$$

We need to compare the above welfare function, with the social welfare function in the case of capital requirements, given by (64) and with the social optimum, given by Eq. (11).

But we can show that $U_R^D = U^*$ and $U_R^C = Re(1-T)$. When $p \rightarrow 0$, the optimal contract with recapitalization defined by Eqs. (29)–(35) becomes identical to the social planner's problem given by Eqs. (3)–(7), as Eqs. (32) and (34) become irrelevant. Then, the expected utility of depositors, U_R^D , given by Eq. (36) coincides with U^* . The

Table 1
Calibration.

γ	η	R	α	T	k	e	λ	β	w	δ_T
0.5	0.4	1.5	0.3	0.3	0.8	0.08	1.1	0.5	0.92	0.03

investors' utility is also identical to the social planner's case, i.e., $U_R^C = Re(1-T)$. Therefore, the welfare function coincides with (11). The intuition for this result is that recapitalization only has a cost when the bad state of the world realizes and thus has zero cost when $p \rightarrow 0$.

On the other hand, the optimal contract with capital requirements does not achieve the first best, due to constraint (57). This is due to the fact that in our model the availability of capital for banking is sufficiently limited, and hence the optimal allocation cannot be achieved. Therefore, $U_{CR}^D < U^*$.

Then, as $U_R^D > U_{CR}^D$ and $U_R^C = U_T^{CR} = Re(1-T)$ it must be that $U_R > U_{CR}$ when $p \rightarrow 0$.

Finally, as the function U_R is decreasing in p while U_{CR} is independent of p , for a sufficiently low p , recapitalization should be preferred.

Q.E.D.

For a given p , we can also find the threshold θ , for recapitalization or the tax on early withdrawals to be preferred to capital requirements. First, recapitalization is preferred to capital requirements when $U_R \geq U_{CR}$, or, equivalently, if

$$\theta \geq \theta^{CR} \equiv \frac{2(U_{CR}^D - U_R^D) + (1-w)(d_2^C - U_R^C)}{p \{w[u\{T(1+e) - \delta\} - u\{T(1+e)\} + \eta u(\kappa\delta)] - (1-w)[\delta - \eta\kappa\delta]\}} \quad (66)$$

Similarly, the tax on early withdrawals is preferred to capital requirements if $U_T \geq U_{CR}$, i.e., for

$$\theta \geq \theta^{CT} \equiv \frac{2(U_{CR}^D - U_T^D) + (1-w)(d_2^C - U_T^C)}{[wu(\kappa\gamma\delta_T) + (1-2)\kappa\gamma\delta_T]} \quad (67)$$

6. Numerical simulations

In order to explore the relevance of the different intervention policies some numerical simulations are carried out.¹⁴ The following utility function is assumed:

$$U^i(c_i) = \frac{c_i^{1-\beta}}{1-\beta}; \quad (i = 1, 2) \quad (68)$$

Table 1 summarizes the calibration of the model. For these parameter values all the equilibrium conditions of the model are satisfied.

Most of the values of the parameters are consistent with those already used in previous papers, for example $T=0.3$ is close to the value used in Hugonnier and Morellec (2014), and those values selected for α , λ , γ and R were already used in Hasman et al. (2013), the ratio of capital over deposits ($e/D=0.08$) is similar to the one employed in Kashyap et al. (2014). Finally, the value of η is low enough so that the bank-run condition is always satisfied. All the previous mentioned papers used different models to the one developed here, meaning that the values not only satisfied all the conditions required by our model but are also quite standard in the literature. Additionally, we have run comparative statics to analyze the sensitivity of our results to changes in the parameters, and the results are robust to such changes.

¹⁴ The computational procedure is detailed in Appendix A. The program is available from the authors upon request.

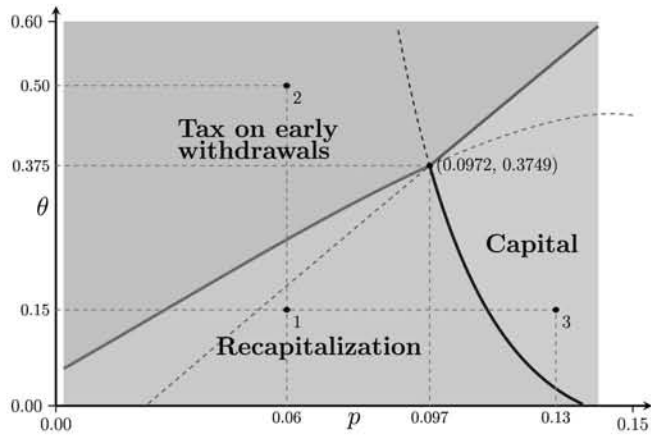


Fig. 2. Regions for θ and p .

Fig. 2 displays the comparison among the different policy measures i.e., recapitalization, the tax on early withdrawals and capital requirements when the weights assigned to both groups of agents (depositors and investors) in the social welfare function is proportional to their initial wealth, i.e., $w = 1/(1 + e)$ (This assumption will be modified later on).

We distinguish three level curves that represent the combinations (p, θ) for which two measures yield the same expected utility. For example, the blue line (θ_{CR}) gives the combinations of the parameters for which capital requirements and recapitalization yield the same expected utility, i.e., Eq. (66). It can be seen that in the eastern part capital requirements is the dominant policy, while in the western part recapitalization would be preferred. The green line (θ_{TR}) represents the combinations of (p, θ) , for which the tax on early withdrawals and recapitalization yield the same expected utility, i.e., Eq. (55). In this case, the tax on early withdrawals dominates in the northern region and recapitalization in the southern one. Finally, the red line (θ_{CT}) gives the combinations of (p, θ) for which capital requirements and the tax on early withdrawals yield the same expected utility, i.e., Eq. (67). In this case, the tax on early withdrawals dominates in the western region and capital requirements in the eastern one. It should also be mentioned that in all simulations bank runs are always dominated by the intervention policies. This may be due to the high costs that bank runs impose on risk-averse individuals.

In Fig. 2, we distinguish three clear regions that represent different policy choices. The blue region represents a clear dominance of the tax on early withdrawals with respect to the other policies. In the green region the best policy in hands of the government is capital requirements, and finally, in the red region the optimal policy is recapitalization. The intuition is that when individuals highly value public services (θ is high), then the best policy in terms of welfare is to apply a tax on early withdrawals, as the government can transfer those taxes to the whole population by investing in the public asset (although at some cost κ). Conversely, when θ is low, recapitalization is the dominant policy. Finally, capital requirements should be imposed when the probability of a bank run is sufficiently high.

Table 2 presents an example of the different allocations that are achieved with the three measures, at the points 1, 2 and 3 represented in Fig. 2. It can be checked that in point 1, recapitalization is the dominant policy, in point 2 the tax on early withdrawals dominates and in point 3, the capital requirement is welfare superior.

6.1. Comparative statics

Fig. 3 shows the optimal choices for low and high values of w (weight assigned to depositors in the social welfare function). Note

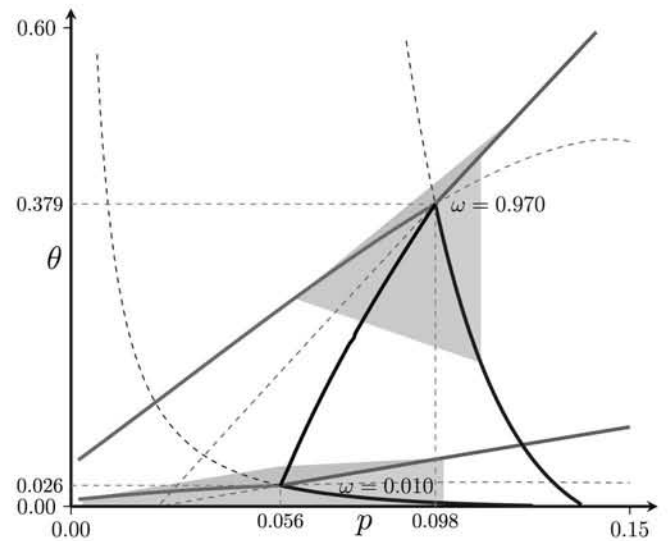


Fig. 3. Regions for θ and p with w variable.

that when the government assigns low values to depositors in the social welfare function, we see that for a given low p , the tax on early withdrawals is preferred to recapitalization for a larger set of parameters.

The main reason is that the tax on early withdrawals affects only impatient depositors but the revenue created by this policy might return to the whole society (depositors and investors) in terms of higher consumption of public goods when the crisis does not appear. On the other hand, for high values of w , recapitalization crowds out the tax on early withdrawals. The black line represents how the critical point that separates the three regions changes, as w changes.

Figs. 4–7 carry out a comparative analysis, in order to see how the three regions are affected by variations in the different parameters of the model. We have carried out 300 maximization problems for each level curve. We have analyzed the effects on the space (p, θ) of modifying R (return on the long-term asset), γ (proportion of impatient depositors), T (taxes) and κ (cost of late consumption of the public asset).

We proceed running simulations in order to analyze the effects of changing the parameters of the model using as the benchmark $w = 1/(1 + e)$ (with $w = 0.9$).

Fig. 4 presents the effects of modifying R . We see that as R increases, the critical point that separates the three regions moves up and to the right. This is due to the fact that when R is high, the opportunity cost of capital is also high and consequently capital requirements become very costly.

Table 2
Values at the given points.

		c_1	c_{2h}	c_{2l}	x	d_{2h}	Welfare funct.
1	Tax	0.5868	1.2180	0.0000	0.4626	0.0849	1.8578
	Recap.	0.6372	1.1419	0.0000	0.4374	0.0852	1.8806
	Capital	0.8400	0.8400	0.0000	0.3360	0.0840	1.8652
2	Tax	0.5868	1.2180	0.0000	0.4626	0.0849	2.3062
	Recap.	0.6372	1.1419	0.0000	0.4374	0.0852	2.2558
	Capital	0.8400	0.8400	0.0000	0.3360	0.0840	2.2425
3	Tax	0.6331	1.1450	0.0000	0.4395	0.0867	1.7861
	Recap.	0.7281	1.0003	0.0000	0.3920	0.0873	1.8596
	Capital	0.8400	0.8400	0.0000	0.3360	0.0840	1.8652

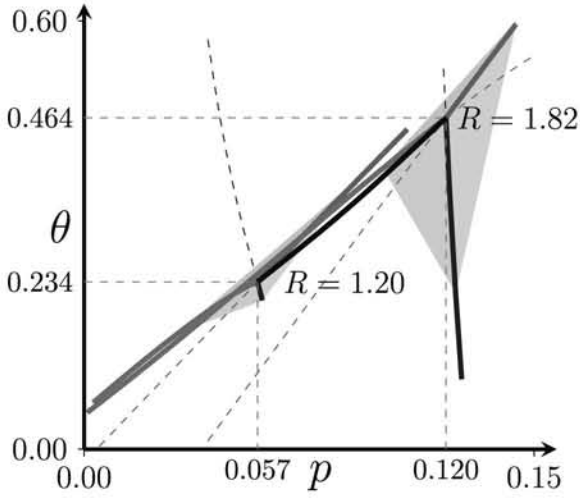


Fig. 4. Regions of R for $\omega = 0.926$.

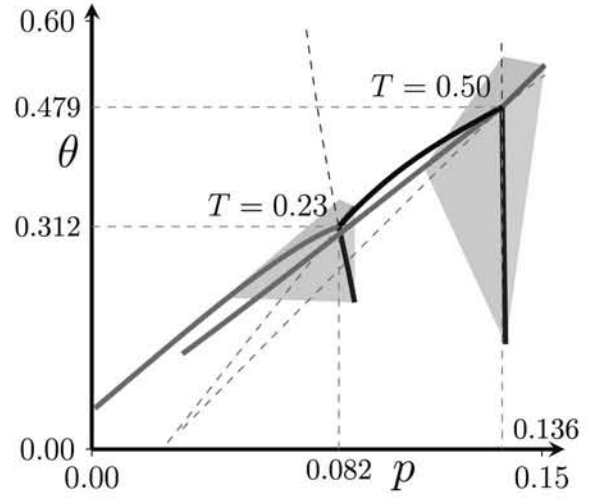


Fig. 7. Regions of T for $\omega = 0.926$.

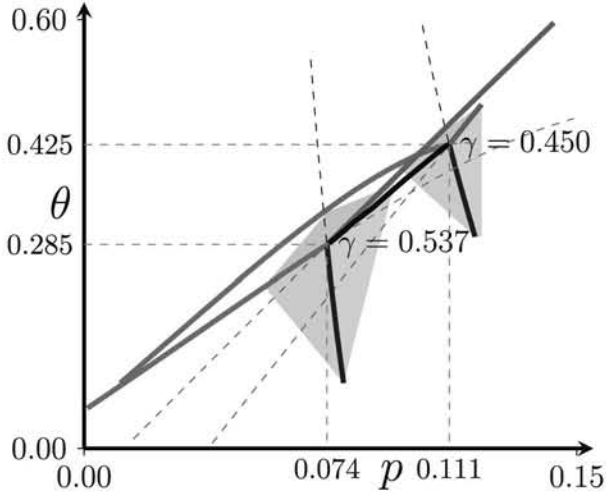


Fig. 5. Regions of γ for $\omega = 0.926$.

Fig. 5 analyzes the effects of modifying the proportion of impatient depositors (γ). Note that as γ increases, the critical point that separates the regions moves to the left. Consequently, the preference for capital requirements increases with the proportion of impatient agents. This is normally the case of emerging economies with a history of crises and where depositors are afraid of keeping their deposits for long time in banks. In those societies, banks would be required to be highly liquid.

Fig. 6 shows the effects of changing k , the discount factor that represents the cost of late consumption of the public asset. We observe that as k decreases, the critical point moves up and to the left. The intuition for this result is that as late consumption of public services becomes more costly (lower k), the region where capital is preferred, increases. The reason is that capital requirements do not affect the consumption of the public good.

Fig. 7 presents results of varying T , the level of taxes. It can be observed that as the level of taxes increases, the critical point moves up and to the right. Both, recapitalization and capital requirements are preferred for a larger set of parameters. This is a clear result, since increasing taxes, has a negative effect on the consumption of

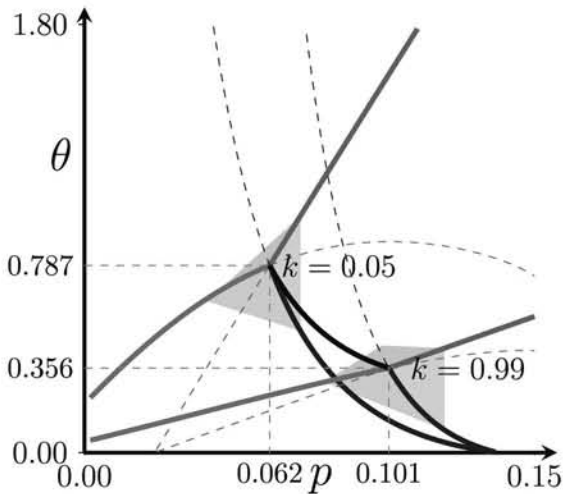


Fig. 6. Regions of k for $\omega = 0.926$.

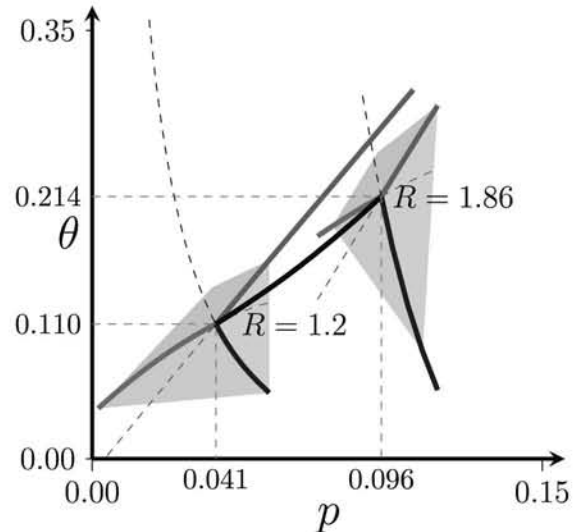


Fig. 8. Regions of R for $\omega = 0.10$.

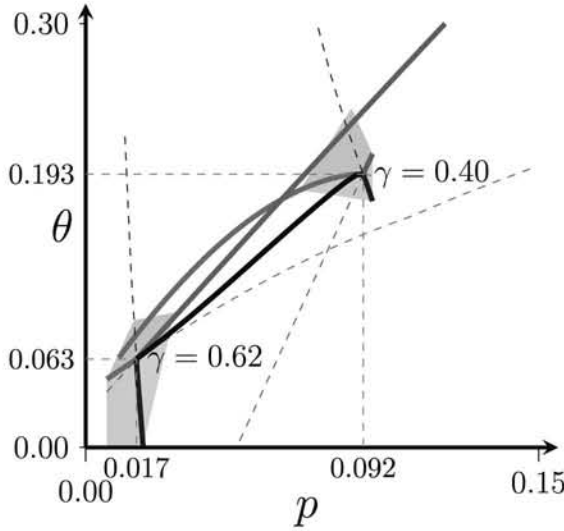


Fig. 9. Regions of γ for $\omega = 0.10$.

the private good. Therefore, the tax on early withdrawals, is more costly in terms of welfare.

Finally, we have replicated all the simulations for low levels of w ($w = 0.1$).

Figs. 8–11 present the effects of modifying respectively, R , γ , T and k . We can observe that the level curves have the same form as those obtained for high values of w . This analysis shows that changes on different parameters of the model have the same marginal effect on the optimal policy choice for different configurations of the social welfare function. Consequently, the social welfare function determines which policy dominates for different combinations of (p, θ) , and this structure of preferences will be maintained for different weights, w . That means that in the northern region the tax on early withdrawals always dominates the other policies, in the southeast region recapitalization will dominate while in the eastern region capital requirements will be the preferred policy.

Table 3 summarizes the main effects on the optimal policies, of changes in the parameters of the model (where + means positive effect, – negative effects, \circ no effect and ? no clear effect):

Table 3
Optimal policies effect.

	R	γ	T	k
Tax	?	–	–	+
Recapitalization	+	?	+	?
Capital requirements	–	+	?	–

7. Concluding remarks

We examine the interaction between a government that raises taxes, provides public services and tries to prevent bank runs, depositors that pay taxes and consume private and public services, and investors that pay taxes, provide capital and consume private and public goods. When banks are insufficiently capitalized, investors have incentives to invest in very risky projects (i.e., there is a moral hazard problem). We show that increasing capital requirements is not always the optimal policy since capital is costly and it reduces the investment on the long-term productive technology.

We show that recapitalization is the optimal policy option when depositors and investors do not value public goods highly (low θ) and the probability of investing in the gambling asset (p) is small enough. Conversely, the tax on early withdrawals should be used for high θ . When the probability p increases, capital requirements is the optimal choice. This structure of preferences applies for different weights of depositors and investors in the social welfare function (w). We show that increasing the long-term asset return (R), has a positive effect on recapitalization and a negative one on capital requirements. Increasing the proportion of agents with liquidity needs (γ) has a negative effect on the tax on early withdrawals and a positive effect on recapitalization. Finally, increasing k , (late consumption of the public asset becomes less costly) has a positive effect on the tax on early withdrawals and a negative one on capital requirements.

Surprisingly, all the parameters have different marginal effects on the optimal policy choice, but this effect is independent of the different weights assigned to depositors and investors in the social welfare function.

Clearly, we find that stopping bank runs is efficient. But on the other side, we have that the policy debate might not be on efficiency but on other arguments like applicability. In that sense, recapitalization (usually controversial) is costly in terms of public services

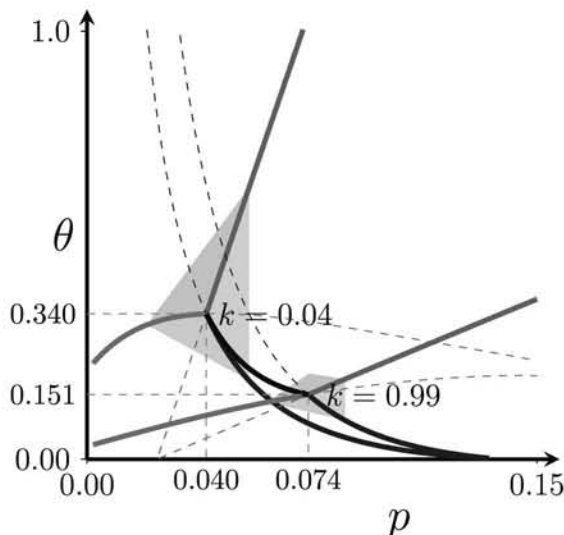


Fig. 10. Regions of k for $\omega = 0.10$.

but can be easily implemented. Capital requirements are costly and difficult to evaluate. The tax on early withdrawals can be easily implemented, it is cheap in terms of public resources, but affects those individuals with real liquidity needs. Other possible solutions might include government borrowing. Although one of the most interesting points of our paper is that we do not need foreign (or not modeled) resources to prevent a bank run. All the resources used to resolve a bank run are modeled and consequently do not generate a burden on future generations nor devalue the currency. Moreover, during a crisis many non-developed countries might find it very hard to get external finance.

Finally, it should be mentioned, as an empirical matter, that the relevance of comparing ex-post recapitalization and capital requirements hinges on the elasticity of the supply of capital to banking. Furthermore, the model has exogenous moral hazard, which evidence indicates is far from the case for bankers. Future research should be devoted to extending the analysis to deal with these issues.

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Appendix A. Computational procedure

The computational procedure to obtain the regions in the parameter space p and θ , given the social welfare functions with recapitalization, the tax on early withdrawals and capital requirements, defined respectively in Eqs. (38), (53) and (64), is as follows:

1. A value for the parameters $e, \beta, \lambda, \eta, R, t, T, \gamma, \alpha, k, w$ and δ_T is fixed.
2. The value of p is divided into 31 equally distributed intervals.
3. Within this p cycle an arbitrary value of θ is chosen.
4. The solutions to the depositor's maximization problems with recapitalization, Eqs. (29)–(35), the tax on early withdrawals, Eqs. (41)–(46) and capital requirements, Eqs. (56)–(61), are obtained, and the corresponding equilibrium conditions are verified.
5. Every couple of these maximization results allows us to obtain the value of θ that gives the separation point between the different regions according to the following criteria:
 - θ^{TR} is obtained from Eq. (55).
 - θ^{CT} is obtained from Eq. (67).
 - θ^{CR} is obtained from Eq. (66).
 - Whenever the values of $\theta^{TR}, \theta^{CT}, \theta^{CR}$ are obtained for each of the 31 values of p , the point that gives the intersection of the three regions needs to be more accurately computed. The procedure is similar to the one explained. It is iterative until the same utility is reached in the three regions. A guess of the p and θ values are computed as the mean value of the three regions

intersections taken two by two. The intersection between two regions is simulated as the straight line obtained with the two nearest pair of p, θ values to the intersection. This allows a quick convergence of the solution.

References

- Acharya, V., Shin, H., Yorulmazer, T., 2011. Crisis resolution and bank liquidity. *Rev. Financ. Stud.* 24 (6), 2166–2205, 2011. 3.
- Acharya, V., Shin, H., Yorulmazer, T., 2007. Too many to fail – an analysis of time inconsistency in bank closure policies. *J. Financ. Intermed.* 16 (1), 1–31.
- Allen, F., Gale, D., 1998. Optimal financial crises. *J. Finance* 53, 1245–1284.
- Allen, F., Gale, D., 2007. *Understanding Financial Crises*. Oxford University Press, Oxford, ISBN: 978-0-19-925141-4.
- Allen, F., Carletti, E., Goldstein, I., Leonello, A., 2013. Government Guarantees and Financial Stability. Working Paper.
- Basel Committee on Banking Supervision, 2004. International Convergence of Capital Measurement and Capital Standards. A Revised Framework. Bank for International Settlements.
- Blum, J., 1999. Do capital adequacy requirements reduce risks in banking? *J. Bank. Finance* 23, 755–771.
- Buser, A.H., Chen, E., Kane, J., 1981. Federal deposit insurance, regulatory policy, and optimal bank capital. *J. Finance* 35 (1), 51–60.
- Brusco, S., Castiglionesi, F., 2007. Liquidity coinsurance, moral hazard and financial contagion. *J. Finance* 62 (5).
- Chari, V., Jagannathan, R., 1988. Banking panics, information and rational expectations equilibrium. *J. Finance* 43 (3), 749–761.
- Corbett, J., Mitchell, J., 2000. Bank crises and bank rescues: the effect of reputation. *J. Money Credit Bank.* 32 (3), 474–513.
- Diamond, D., Dybvig, P., 1983. Bank runs, deposit insurance, and liquidity. *J. Polit. Econ.* 91, 401–419.
- Ennis, H., Keister, T., 2010. Banking panics and policy responses. *J. Monet. Econ.* 57, 404–419.
- Farhi, F., Tirole, J., 2012. Collective moral hazard, maturity mismatch and systemic bailouts. *Am. Econ. Rev.* 102, 6093.
- Furlong, F.T., Keeley, M.C., 1989. Capital regulation and bank risk-taking: a note. *J. Bank. Finance* 13 (6), 883–891.
- Gale, D., 2010. Capital regulation and risk sharing. *Int. J. Cent. Bank.*, 187–204.
- Gorton, G., 1988. Banking panics and business cycles. *Oxf. Econ. Pap.* 40, 751–781.
- Hasman, A., Samartín, M., 2008. Information acquisition and financial contagion. *J. Bank. Finance* 32, 2136–2147.
- Hasman, A., López, Á.L., Samartín, M., 2011. Government, taxes and banking crises. *J. Bank. Finance* 35, 2761–2770.
- Hasman, A., Samartín, M., Van Bommel, J., 2013. Financial contagion and depositor monitoring. *J. Bank. Finance* 37, 3076–3084.
- Hellman, T., Murdock, K., Stiglitz, J., 2000. Liberalization, moral hazard in banking, and prudential regulation: are capital requirements enough? *Am. Econ. Rev.* 90 (1), 147–165.
- Hugonnier, J.N., Morellec, E., 2014. Bank Capital, Liquid Reserves, and Insolvency Risk. Available at SSRN: <http://ssrn.com/abstract=2448162>
- Jeanne, O., Korinek, A., 2013. Macroprudential regulation versus mopping up after the crash. Technical report. National Bureau of Economic Research.
- Kashyap, A., Tsomocos, D.P., Vardoulakis, A.P., 2014. How does macroprudential regulation change bank credit supply? Working Paper No. 20165. National Bureau of Economic Research.
- Koehn, M., Santomero, A.S., 1980. Regulation of bank capital and portfolio risk. *J. Finance* 35, 1235–1244.
- Laeven, L., Valencia, F., 2008. Systemic Banking Crises: A New Database, IMF. Working Papers 08/224.
- Lastrapes, W., Selgin, G., 1997. The check tax: fiscal folly and the great monetary contraction. *J. Econ. Hist.* 57 (4), 859–878.
- Mitchell, J., 2001. Bad debts and the cleaning of banks' balance sheets: an application to transition economies. *J. Financ. Intermed.* 10, 1–27.
- Morrison, A., White, L., 2005. Crises and capital requirements in banking. *Am. Econ. Rev.*, 1548–1572.
- Osano, H., 2002. Managerial compensation contract and bank bailout policy. *J. Bank. Finance* 26 (1), 25–49.
- Repullo, R., 2004. Capital requirements, market power, and risk-taking in banking. *J. Financ. Intermed.* 13, 156–182.